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# Production of autoclaved lightweight concretes using pottery stone and bagasse ash

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**Abstract**

This study investigated the influence of pottery stone and bagasse ash on the mechanical features of autoclaved lightweight concrete. Pottery stone is a natural resource of igneous rock weathering commonly exists with white clay, feldspar and limestone. This raw material is mainly composed of quartz and mica that has been used for the production of ceramic products. Bagasse ash is a waste product of the sugar refining process that causes serious environmental pollution. Pottery stone and bagasse ash waste were physically characterized and partially substituted by the weight of cement in lightweight concrete with the addition of aluminium powder at a certain amount. The use of aluminium powder showed a positive effect on the porosity of lightweight bodies. Compressive strength, density and thermal conductivity were determined. Pottery stone can be used as a natural pozzolan for the production of lightweight concrete. Lightweight concrete manufactured with 17.5% pottery stone and 17.5% bagasse ash showed low density and good compressive strength. Autoclaved lightweight concrete is considered an economy in the consumption of pottery stone and bagasse ash waste as cement replacement, therefore enhancing the possibility of its reuse in a sustainable way.

## 1. Introduction

Challenges of establishing sustainability in Thailand's construction industry are associated with the growth of the gross domestic product and the management of resources and waste that arose throughout the supply chain, including raw materials and waste management, designing and manufacturing process. The concept of circular economy has captured the interest of researcher on how to reuse the remaining materials with the highest efficiency and apply them to the manufacturing cycle to create more efficient use of energy and resources and achieve sustainability. This ensures that new resources for production are reduced and that waste is minimized [1]. As regards, the application of a circular economy can ameliorate waste management and eventually improve recycling both in quality and quantity [2].

Pottery stone is a natural resource of igneous rock weathering, composes of quartz and mica. This raw material is mined in different quarries and has been used as filler or additive in ceramic production [3]. The chemical composition of pottery stone consists mainly of silica and alumina which can be used as a substitute for silica, feldspar and kaolin [4]. Bagasse ash is the residue from the sugar refining process which contains silica and alumina as the dominant chemical composition. Bagasse ash has been attempted to utilize as plastic products, plywood, fuel in electricity production and construction materials as it remained more than 1 million metric tons per year [5]. As pottery stone and bagasse ash contain silica as the major element which has pozzolanic activities during the hydration reaction and pozzolanic reaction. Few studies have been focused on the pozzolanic activity of bagasse ash and its suitability as a cement replacement for the construction industry [6,7]. The use of pottery stone and bagasse ash as the raw materials for the production of autoclaved lightweight concrete would be advantageous for the environment in terms of cement replacement and also waste recycling.

Lightweight concretes are one of the main nonstructural parts that become popular with the construction industry and economic growth due to their attractive properties in sound and thermal insulation, lightweight and resistance to pressure [8]. For broadening the use of pottery stone and bagasse ash, this study describes the production of autoclaved lightweight concrete with the presence of pottery stone and bagasse ash in the mixture formulas. Here the different amounts of pottery stone and bagasse ash used for cement replacement were mixed with cement, sand, water and aluminium. The lightweight concrete was then produced through the casting and autoclave process. To characterize the autoclaved lightweight concrete, phase and chemical composition were analyzed. Additionally, the density, compressive strength and thermal conductivity of autoclaved lightweight concrete were investigated.

## 2. Experimental

### 2.1 Raw materials

Pottery stone and bagasse ash were randomly collected from Lampang and Nakorn Sawan province in Thailand, respectively. Both materials were dried at a temperature of 110°C for 24 h and screened through the no.200 mesh sieve. The aluminium powder which was obtained from Nakorn Sawan province in the form of dross from the refining operations was chosen as the foaming agent while sodium silicate ($Na_2SiO_3$) was used as a binder. Local raw material from Thailand, namely cement, sand and lime were screened through the No. 200 mesh sieve and stored in sealed plastic bags.

## 2.2 Batching and casting

Pottery stone and bagasse ash were mixed with varying amounts from 0 wt% to 45 wt% and 0 wt% to 25 wt% of solid weight, respectively (Table 1). Aluminium powder content of 0.30% and $Na_2SiO_3$ content of 0.5 mL were then added and the mixture was blended in a Hobart bowl with the designated amount of water to obtain a homogeneous paste. The mixture was then immediately placed into the mold in the dimension of 5 $cm^3$ × 5 $cm^3$ × 5 $cm^3$. The demolded samples thus produced were placed in an autoclave for 4 h, working at the pressure in the range of 1.75 MPa to 2 MPa to achieve a chamber temperature of at least 200°C.

## 2.3 Characterization

The developed crystalline phases and the chemical composition were analyzed using an X-ray diffractometer (D8 Advance, Bruker, Germany) and X-ray fluorescence spectroscopy (As-8, Bruker, Germany), respectively. According to Archimedes' principle, the density was calculated from weight and volume measurements. The compressive strength was determined by a universal testing machine (AG-Xplus, SHIMADZU, Japan). The thermal conductivity was examined by a laser flash analyzer (HFM 436 Lambda, NETZSCH, Germany).

# 3. Results and discussion

## 3.1 Pore structure of lightweight concrete

The chemical composition analyses of pottery stone and bagasse ash were determined by X-ray fluorescence techniques (XRF) and the results were shown in Table 2. The composition of major oxides of $SiO_2$ and $Al_2O_3$ were shown because of the presence of quartz whereas $Fe_2O_3$ and $TiO_2$ were existence in small quantities. Another important component was the total of alkali and alkaline earth oxides ($Na_2O$, $K_2O$, CaO and MgO) that performing as flux materials were slightly high in both pottery stone and bagasse ash.

The cement mixtures reacted with water to initiate a porous cement gel during the blending process. The gel volume consisted mainly of calcium-silicate-hydrate (C-S-H) products in which calcium hydroxide was amalgamated and developed as the cement hydration reaction continues. Pottery stone and bagasse ash acted as cement replacement for lightweight concrete production that can play the role of effective pozzolan leading to enhance the pozzolanic reaction. Chemical reactions during hydration reaction and pozzolanic reaction were as shown in Equation (1-4) [9,10].

Hydration reaction

$$2(3CaO\cdot SiO_2) + 6H_2O \rightarrow 3CaO\cdot 2SiO_2\cdot 3H_2O + 3Ca(OH)_2 \quad (1)$$

$$2(2CaO\cdot SiO_2) + 4H_2O \rightarrow 3CaO\cdot 2SiO_2\cdot 3H_2O + Ca(OH)_2 \quad (2)$$

Pozzolanic reaction

$$3Ca(OH)_2 + 2SiO_2 \rightarrow 3CaO\cdot 2SiO_2\cdot 3H_2O \quad (3)$$

$$3Ca(OH)_2 + 2Al_2O_3 \rightarrow 3CaO\cdot 2Al_2O_3\cdot 3H_2O \quad (4)$$

The foaming agent used to obtain lightweight concrete was aluminium powder. This material reacted with lime as the source of calcium hydroxide and the calcium hydroxide product of the hydration reaction between cement and water. This reaction as shown in Equation (5) caused forming of hydrogen gas and bubbles up out of the mixture and was displaced by air. The volume expansion of lightweight concrete was dependent upon the amount of aluminium powder [11].

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaO\cdot Al_2O_3\cdot 6H_2O + 3H_2 \quad (5)$$

Figure 1 shows the cross-section of lightweight samples with different amount of raw materials. Higher pottery stone content in lightweight concrete (A1 to A3) exhibited a greater number of large air bubbles with diameter of bubbles ranging from 0.1 mm to 1 mm distributed in the concrete mix. While the cement percentage increased (A4 to A6), the samples were made up of the additional small bubbles, with pores having sizes between 0.01 mm to 0.1 mm randomly spread throughout the lightweight concrete. The sample A7 with the mixture containing pottery stone, bagasse ash and cement in the ratio of 17.5:17.5:10 revealed the different pore sizes in the lightweight structure. Moreover, the samples with the addition of bagasse ash (A8 to A9) showed a larger amount of micro-pores.

**Table 1.** Batch compositions.

| Samples | Composition (%) | | | | |
|---|---|---|---|---|---|
| | Pottery stone | Bagasse ash | Cement | Sand | Lime |
| A1 | 45 | 0 | 0 | 25 | 30 |
| A2 | 40 | 0 | 5 | 25 | 30 |
| A3 | 35 | 0 | 10 | 25 | 30 |
| A4 | 30 | 0 | 15 | 25 | 30 |
| A5 | 25 | 0 | 20 | 25 | 30 |
| A6 | 20 | 0 | 25 | 25 | 30 |
| A7 | 17.5 | 17.5 | 10 | 25 | 30 |
| A8 | 0 | 25 | 20 | 25 | 30 |
| A9 | 0 | 20 | 25 | 25 | 30 |

**Table 2.** Chemical compositions (wt%) of pottery stone and bagasse ash.

| Raw materials | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $TiO_2$ | Other |
|---|---|---|---|---|---|---|---|---|---|
| Pottery stone | 77.14 | 14.16 | 0.58 | 0.32 | 0.12 | 4.96 | 2.46 | 0.04 | 0.22 |
| Bagasse ash | 71.22 | 6.92 | 4.17 | 8.61 | 2.12 | 0.23 | 3.80 | 0.57 | 2.33 |

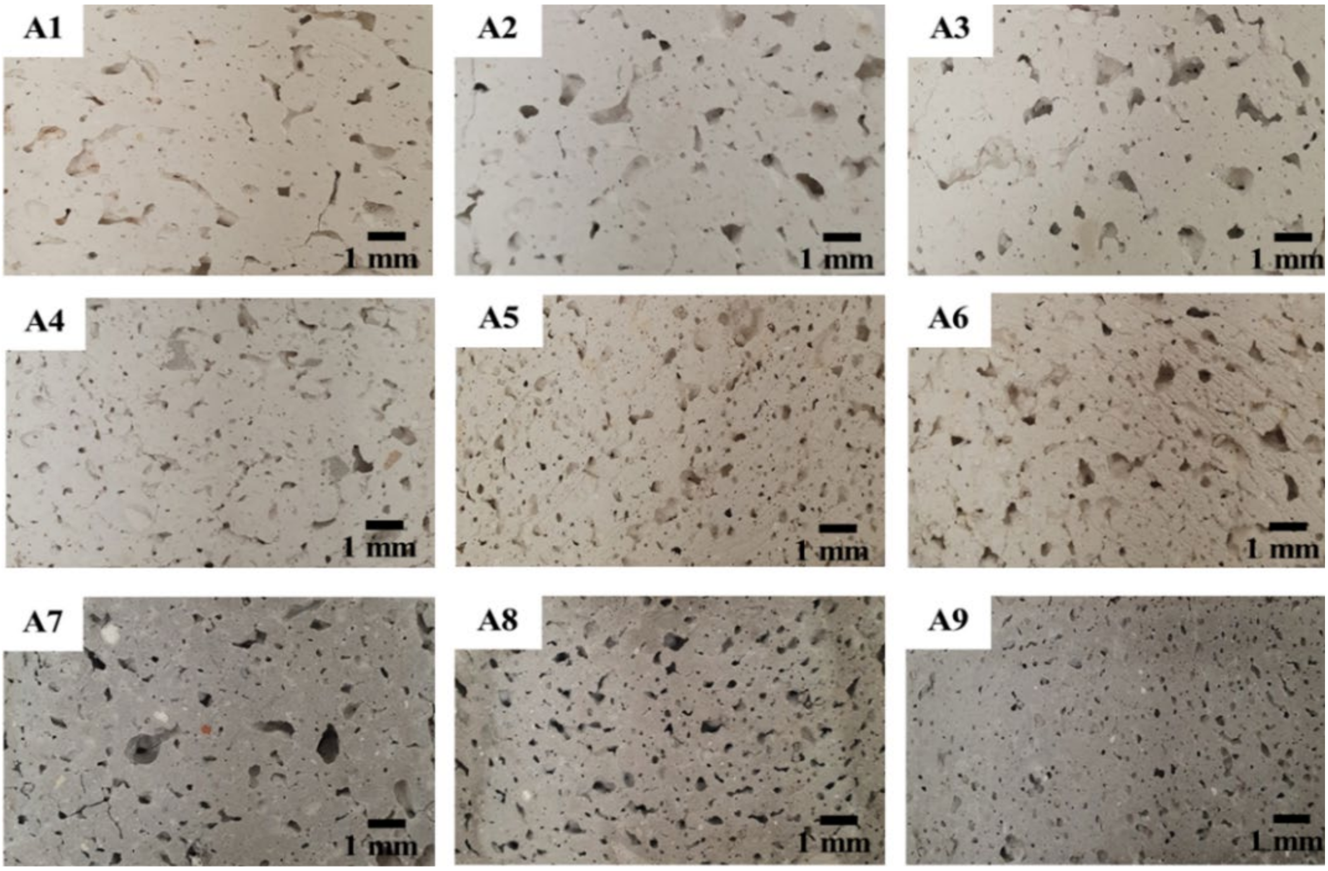


**Figure 1.** Cross-section of samples with different amount of raw materials: A1 to A9.

## 3.2 Density and water absorption

Pottery stone had a bulk density of 0.58 g·cm$^{-3}$ which is higher than bagasse ash obtained by 0.34 g·cm$^{-3}$. In addition, typical lightweight concrete had a density in the range of 1.44 g·cm$^{-3}$ to 1.84 g·cm$^{-3}$ compared to normal concrete with a density on the order of 2.24 g·cm$^{-3}$ to 2.40 g·cm$^{-3}$ [12,13]. Figure 2 presents the density of samples from A1 to A9. The density was determined primarily by a composition of the mass and volume. According to the addition of aluminium powder, the pore generated from the release of gas during mixing had a low density as it can be seen that the density of samples: A1 to A9 were in the range of 0.77 g·cm$^{-3}$ to 1.25 g·cm$^{-3}$. The densities of lightweight concrete samples containing 25% to 45% pottery stone (A1 to A5) were greater than 1.00 g·cm$^{-3}$. In comparison with TIS 2601-2556, the test results of the sample A6 with the density of 0.86 g·cm$^{-3}$ reached the standard class C9. In addition, the samples A7, A8 and A9 attained the standard class C10, C10 and C8, respectively [14]. With the bagasse ash and cement percentage increasing, it was found that the number of pores increased and then the density decreased. Different pozzolan resources such as bagasse ash and pottery stone gave different results in pozzolanic reaction during the lightweight concrete production which affected the density, mechanical properties and phase composition [13]. Pottery stone was more pozzolanic reactive than bagasse ash as it was observed that sample A6 with the addition of 20% pottery stone showed higher density than sample A9 with 20% bagasse ash.

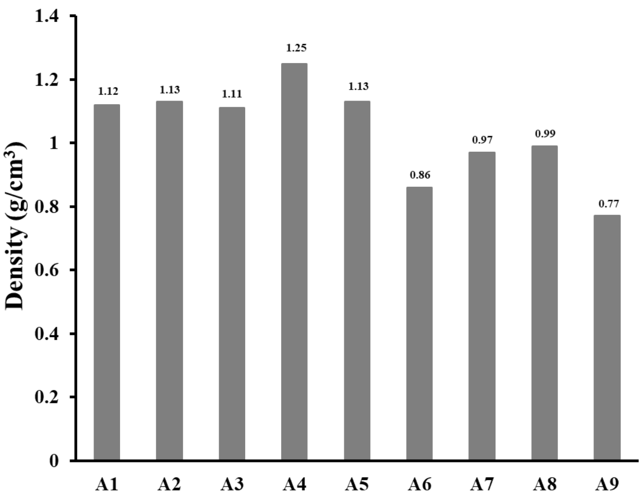


**Figure 2.** The density of lightweight concrete samples from A1 to A9.

### 3.3 Compressive strength

TIS 2601-2556 standard classifies specification of lightweight concretes by bulk density and compressive strength. The minimum compressive strength of lightweight concrete for the standard class C8 is 2.0 MPa (Sample A9) and the standard class C9-C12 is 2.5 MPa (Sample A6 to A8) [14]. Figure 3 shows the sample compressive strength varied between 2.04 $N{\cdot}mm^{-2}$ to 6.05 $N{\cdot}mm^{-2}$. The sample in which aluminium powder was added will generate more pores, leading to the decrease in density and compressive strength. It was found that the addition of 35% to 45% pottery stone (A1 to A3) affected the mechanical properties of the samples by increasing of compressive strength and also density. The highest compressive strength at 6.05 $N{\cdot}mm^{-2}$ was remarked on sample A3 made from 35% pottery stone and 10% cement. However, the use of pottery stone in the range of 20% to 30% (A4 to A6) showed lower compressive strength. The lowest compressive strength at 2.04 $N{\cdot}mm^{-2}$ was observed with sample A6 made from 20% pottery stone and 25% cement. With an increase in bagasse ash percentage, the compressive strength of the samples (A7 to A9) were developed to a range of 2.69 $N{\cdot}mm^{-2}$ to 3.53 $N{\cdot}mm^{-2}$.

### 3.4 Phase composition

XRD patterns of lightweight samples (A6-A9) fabricated using an autoclave process are exhibited in Figure 4. According to the crystallographic phase quantification obtained, the samples contained quartz (ICDD No. 01-070-7344), tobermorite (ICDD No. 01-075-6779) and calcite (ICDD No. 00-047-1743) as main phases. The main peak for tobermorite was discovered at around 2θ of 7° to 8°. Tobermorite is a calcium silicate hydrate mineral that was formed during the hydration process in an alkaline environment. The morphology and quantity of tobermorite can affect the internal surface area, mechanical properties and thermal insulation of the lightweight concrete. Riversidite is the peak located close to the tobermorite peak which was found in samples A6-A7.This indicated dehydration and shrinkage in the c crystallographic direction [15,16]. Therefore, the normal and anomalous tobermorite were obtained from the samples made using pottery stone.

### 3.5 Thermal conductivity

Thermal conductivity of lightweight concrete which is the number of Watts conducted per metre thickness in a direction perpendicular to the surface of the sample, per degree of the temperature difference between two sides ($W{\cdot}m.K^{-1}$) was evaluated using a heat flow meter to confirm the heat insulation of sample [17]. The addition of aluminium powder in the mixture resulted in a decrease in density that translates to a decrease in the thermal conductivity of lightweight concrete (Table 3). The samples A6 and A9 revealed thermal conductivity in the range of 0.27 $W{\cdot}m.K^{-1}$ to 0.48 $W{\cdot}m.K^{-1}$ measured in the temperature range from 25 °C to 250°C. Thermal conductivity decreased with an increase in the number of pores thus promoting the heat insulation property of the lightweight concrete.

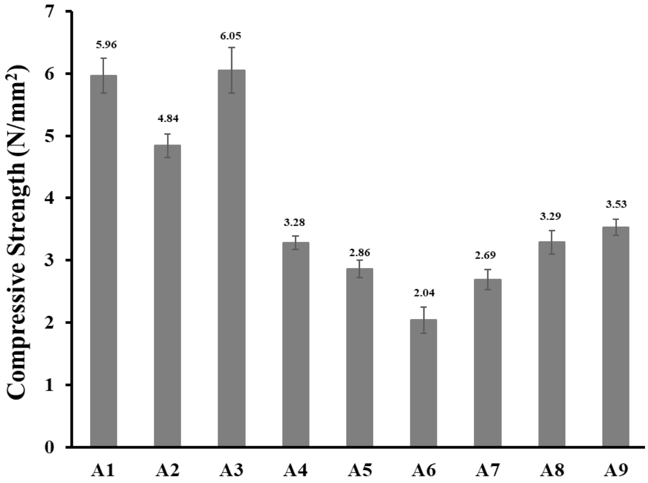


**Figure 3**. The compressive strength of lightweight concrete samples from A1 to A9.

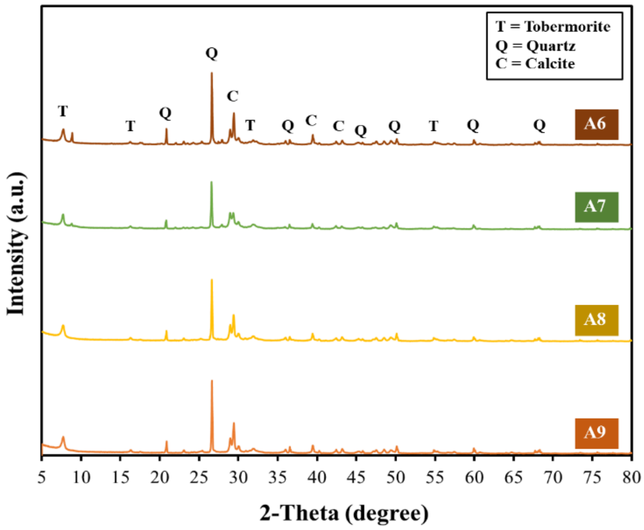


**Figure 4.** XRD patterns of lightweight concrete samples from A6 to A9.

**Table 3.** Thermal conductivity of the lightweight concretes.

| | Thermal Conductivity ($W{\cdot}m.K^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | **25°C** | **50°C** | **100°C** | **150°C** | **200°C** | **250°C** |
| **A6** | 0.30 | 0.31 | 0.33 | 0.36 | 0.39 | 0.38 |
| **A7** | 0.45 | 0.56 | 0.59 | 0.64 | 0.71 | 0.80 |
| **A8** | 0.33 | 0.33 | 0.30 | 0.41 | 0.46 | 0.78 |
| **A9** | 0.27 | 0.28 | 0.32 | 0.43 | 0.45 | 0.48 |

## 4. Conclusions

Lightweight concrete has been developed via an autoclaved aerated process by using pottery stone and/or bagasse ash as the raw materials with the addition of aluminium powder. Pottery stone and bagasse ash showed a property of being pozzolan that can enhance the mechanical properties of lightweight concrete. The compressive strength of lightweight concrete increased with the increase of pottery stone. While aluminium powder showed a positive effect on the porosity of lightweight concrete. Testing of the lightweight concrete with the addition of bagasse ash gave a promising increase in compressive strength and a decrease in density. In comparison with TIS 2601-2556, the test results of the lightweight concretes reached the standard criteria. Further study into the optimization of lightweight concrete is recommended for improved density and compressive strength. This work demonstrates a simple production concept for making lightweight concretes which would be advantageous for the environment in terms of recycling and reuse approaches.

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